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UTILIZATION OF A TRANSMITTING ARRAY MATCHED TO INDIVIDUAL MODES--ETC(U)

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NAVAL UNDERWATER SYSTEMS CENTER
Newport, Rhode Island 02840

(9) Technical ~~Memorandum~~

(6) UTILIZATION OF A TRANSMITTING ARRAY MATCHED TO INDIVIDUAL MODES.

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1 This memorandum consists of the abstract, text, and figures of a paper presented by the author at the Eighty-Fourth Meeting of the Acoustical Society of America in Miami, Florida, on 29 November 1972. A more detailed account of this material will be contained in a NUSC report by the author: "Utilization of an Array Matched to Individual Modes; A Computer Program to Calculate Normal Mode Propagation Using A Transmitting Array".

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ABSTRACT

A vertical transmitting array was implanted in Block Island Sound in November 1970. A theoretical study was undertaken to determine the optimum utilization of such an array to excite individual normal modes. The results of this study are described. Two basic methods to emphasize individual modes, amplitude and phase matching, are outlined. The bases of these methods are derived from the basic properties of modes. Sample cases using these approaches were run using a computer program. The physical characteristics of the implanted array and BIFI velocity profiles typical for summer and winter were assumed. Propagation loss was calculated for individual modes when the array was matched in turn to modes 1-4. For each profile and mode, three methods of emphasizing individual modes, two amplitude matching and one phase matching method, were evaluated.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

The Naval Underwater Systems Center is engaged in shallow water investigations for the purpose of formulating an accurate model suitable for sonar performance prediction. Towards this end a study of normal mode propagation in shallow water is being conducted. A primary experimental tool used in this study is a vertical array of 25 sound projectors shown in Figure 1 at point N near Block Island in the BIFI range. This array has been designed for use in exciting individual normal modes. The excitation of individual modes has many possible uses. Individual modes may be studied. In addition the effect of interference between modes may be reduced. Further it is possible to select for excitation a mode which either maximizes the level of the sound field or selectively provides information about a portion of the water column in which there is interest. This paper describes the initial stages of a theoretical investigation undertaken to determine the optimum utilization of such an array to excite individual normal modes.

AMPLITUDE MATCHING

One method of exciting individual modes is to match an array to the vertical amplitude distribution of the mode. The basis of this method is illustrated in Figure 2 in the idealized case where pressure release surfaces are assumed at the boundaries. The pressure amplitude P_a at any fixed range and depth is proportional to the displacement potential $\phi_m(z_o)$ corresponding to mode m at the source depth as shown in relation (1). It can be seen in the sketch below that $\phi_m(z_o)$ is either positive or negative, depending upon the source depth. Relation (2) gives the pressure amplitude at any fixed range and depth produced by a vertical array of point sources. The contributions of the individual elements are summed for the N array elements. The term in brackets gives the amplitude and phase shading of a given element. In order to maximize P_a for a given mode we make use of the orthogonality property of the modes given by Eq. (3). It follows from (3) and (2) that, for a continuous vertical array of point sources matched to mode n as given by Eq. (4), all arrivals corresponding to the matched mode will add in phase. Arrivals corresponding to all other modes completely cancel each other.

Thus far we have considered mode matching while assuming a medium bounded by two pressure release surfaces. It is more realistic to assume a semi-infinite liquid bottom so that there is a sharp discontinuity in density and sound velocity at the water-bottom interface. Pekeris and others have shown that the modes are no longer orthogonal for such a bottom. Hence matching to a mode will emphasize this mode in the sound field but will not completely eliminate all other modes. The results of matching in this manner have been calculated with a computer program developed for this purpose and theoretical results for a 25-element array and typical BIFI velocity profiles are presented later.

In a study conducted by A. D. Little a simple method of amplitude matching was proposed. This form of matching is illustrated in Figure 3 in the case of mode 2. The displacement potential ϕ is normalized so that its maximum value is 1. A given array element is either turned on or off depending upon the magnitude of ϕ at the element depth. The phase associated with the element is either 0 or 180 degrees. If ϕ is greater than 1/2 the element is turned on and its phase is set at 0 degrees. If ϕ is less than -1/2 the element is turned on and its phase is set to 180 degrees. If the absolute value of ϕ is less than 1/2 the element is left off. The two methods of amplitude shading described above are compared later in a description of the results of tests using the previously mentioned computer program.

PHASE MATCHING

Another approach toward the goal of emphasizing one mode in the sound field is matching the vertical phase shading of an array to that of the desired mode. The basis of this method is illustrated in Figure 4 for the idealized case where density and sound velocity are constant in the water column and pressure release surfaces are assumed at the boundaries. As shown in the figure the plane wave corresponding to mode m must propagate in a direction such that Δ, the advance in phase which occurs as the wave progresses from the top to bottom, is given by $m\pi$. In matching a vertical array to mode m the phases of the elements vary linearly with the depth from 0 to $m\pi$.

The pressure amplitude of a mode as a function of depth can be determined by adding upgoing and downgoing waves corresponding to the mode as shown in the left of Figure 5. Such amplitude distributions are shown to the right on the figure for modes 1 and 2. Similarly the phase of either of the waves at any particular water depth can be determined from the amplitude distribution as a function of depth. The phase of a wave corresponding to mode m at a given depth can be determined simply by calculating the arcsine of the normalized amplitude distribution at the depth of the element. A form of cosine weighting is used to determine the amplitude of each array element.

EVALUATION OF METHODS

A computer program, which is used to determine the amplitude and phase of array elements necessary for the previously described amplitude and phase matching, has been written. In addition, the program, assuming a vertical array of point sources, uses normal mode theory to predict acoustic propagation in a medium over a bottom whose depth and acoustic properties vary with range.

Sample cases were run on a computer in order to evaluate the three methods of mode matching outlined previously. The methods were evaluated through calculations of the theoretical strength of the matched mode in the sound field and the extent to which other modes are depressed in the field. In all cases input parameters to the program included the physical structure of the 25-element BIFI array as well as velocity profiles typical of the BIFI range for summer and winter. All calculations were performed at a frequency of 1000 Hz and a constant 110 foot water depth was assumed. In order to eliminate the influence of receiver position only relative values of signal are considered.

The received levels were calculated at a fixed receiver when the array is matched in turn to each of the modes 1-4. For both summer and winter conditions the three matching procedures outlined previously were used. For both seasons and all modes the relative levels of the modes corresponding to the three procedures were constant to 0.1 dB. These levels are given in

Figure 6. The levels of the matched modes were highest for exact amplitude matching. The amplitude matching using either +1 or -1 weighting produced a signal level only 0.4 dB below that produced by exact amplitude matching. Matching to the phase of the progressive wave associated with the desired mode produced levels 1.3 dB below that of exact amplitude matching.

In Figure 7 the levels of the modes which are not being matched are listed for summer and winter. These levels are a measure of the rejection of unwanted modes. The levels are given relative to the level of the mode when it is being matched. (This level is set arbitrarily to 0 dB). These levels are obtained by the following procedure. First the level of a given mode is calculated when the array is matched to this mode. Next the level of this mode is calculated when the array is matched in turn to each of the other three modes and an average of these three levels is then calculated. The tabulated numbers represent the difference in dB between the level obtained when the array is matched to the mode and the average level of the mode when the array is matched to other modes. It can be seen that the levels of the modes not matched are about 20 dB below the level of those being matched. It can also be seen that the unmatched modes are less depressed in the summer than in the winter. This can be attributed to the increasing penetration of energy into the bottom during the summer and the resulting relatively inefficient mode matching. It can also be seen that phase matching has the least effect in depressing unmatched modes.

CONCLUSIONS

To summarize, three mode matching procedures and their evaluation using a computer program were described. An array may be used either to match the vertical amplitude distribution of a mode or the phase of the progressive wave associated with the mode. It was found that all methods, in theory, would successfully emphasize any desired mode and depress all others under a variety of thermal conditions. Amplitude matching was found to provide more desirable characteristics in the sound field than phase matching. This may be a result of the less than optimum amplitude shading used in the phase matching procedure. The rough amplitude matching proved to be an excellent approximate matching procedure. The necessary amplitude and phase of each array element for all procedures is provided by a computer program. The BIFI range contains a vertical transmitting array which can be used to excite individual modes using any of the procedures discussed. An experimental effort is being made to test these procedures.

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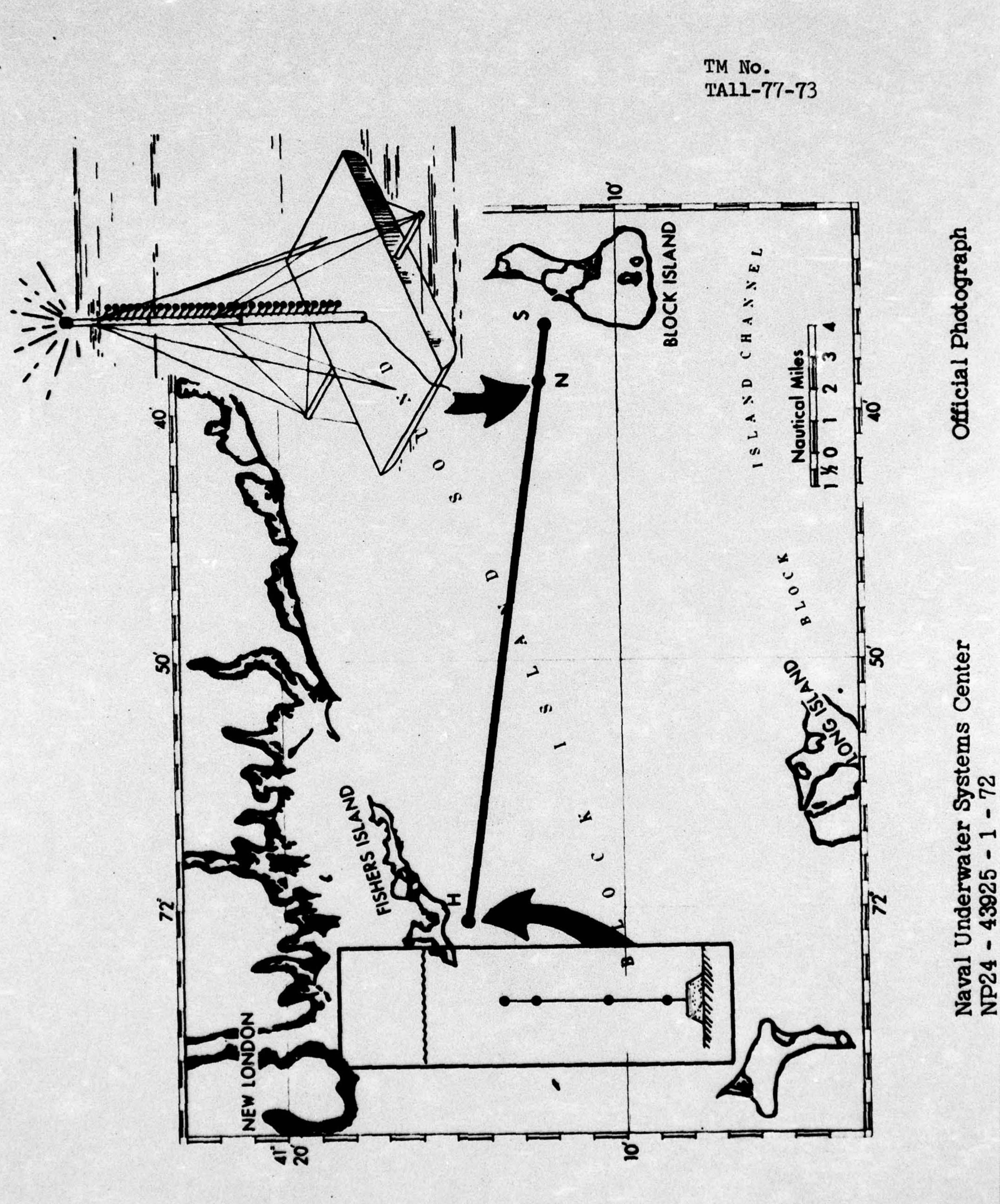

Figure 1

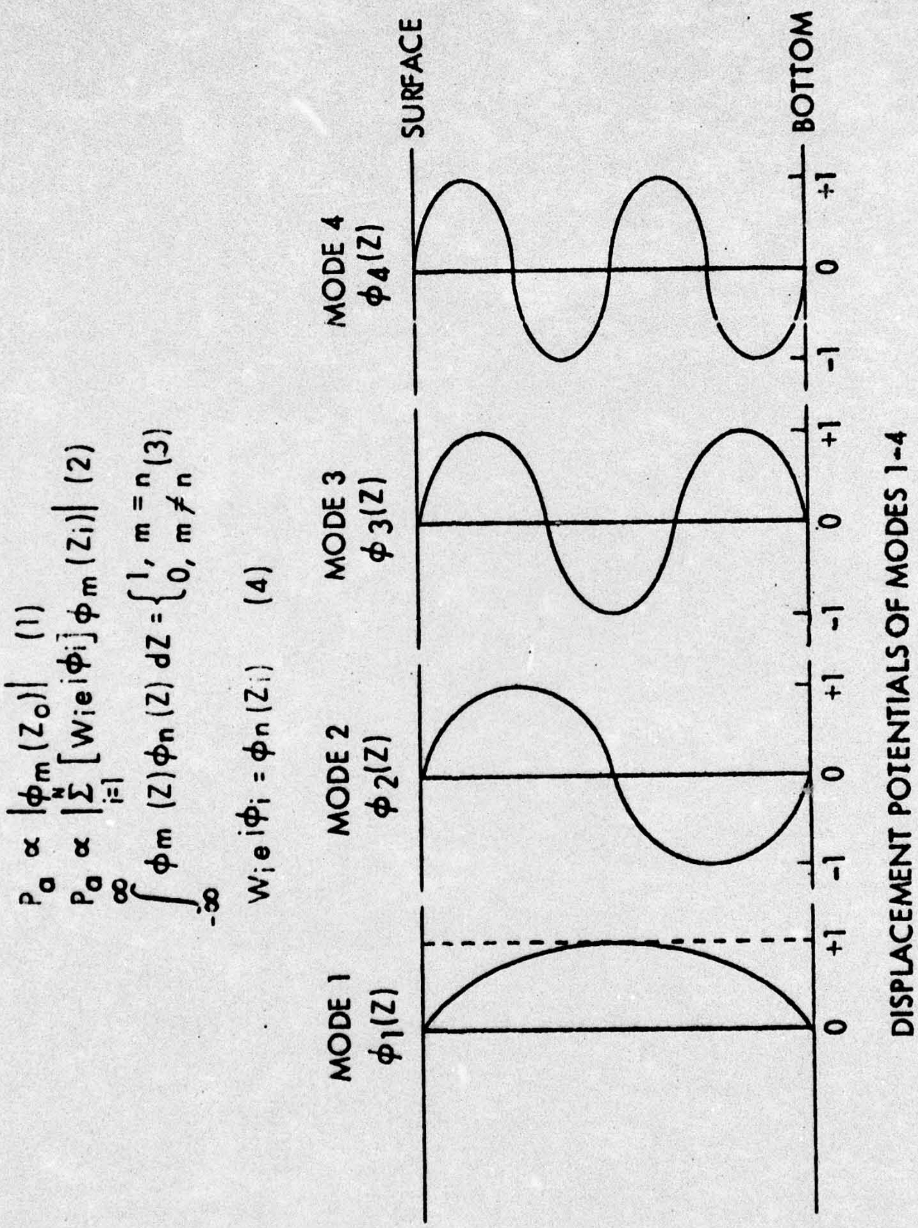

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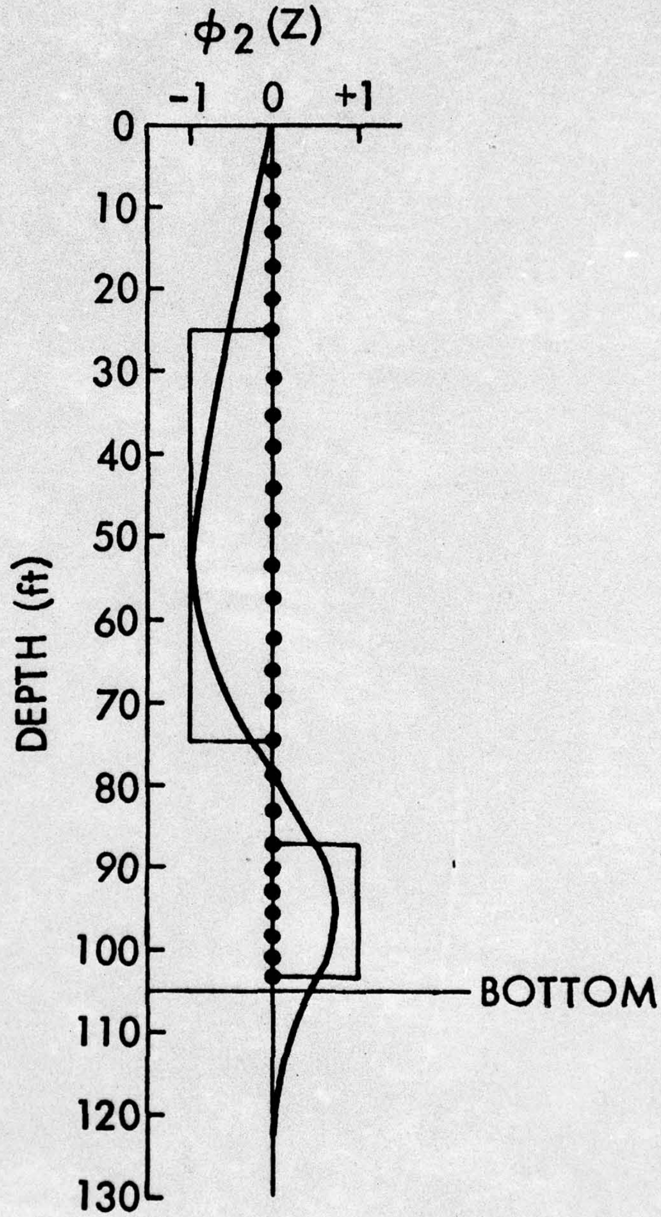
Figure 2



OPTIMUM DRIVING PATTERN FOR ARRAY-MODE 2

Figure 3

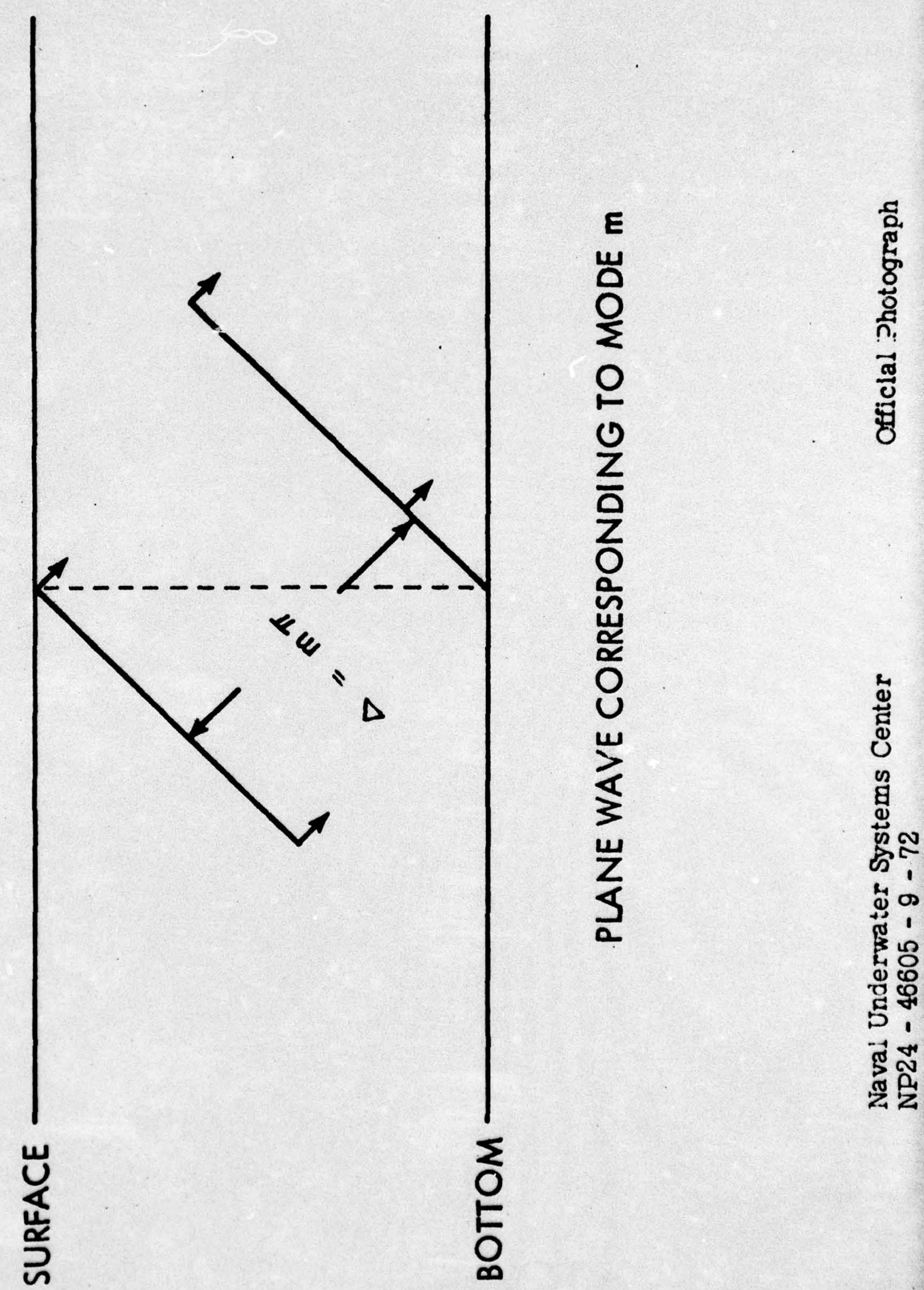

PLANE WAVE CORRESPONDING TO MODE m
SURFACE
BOTTOM
Δ = mπ
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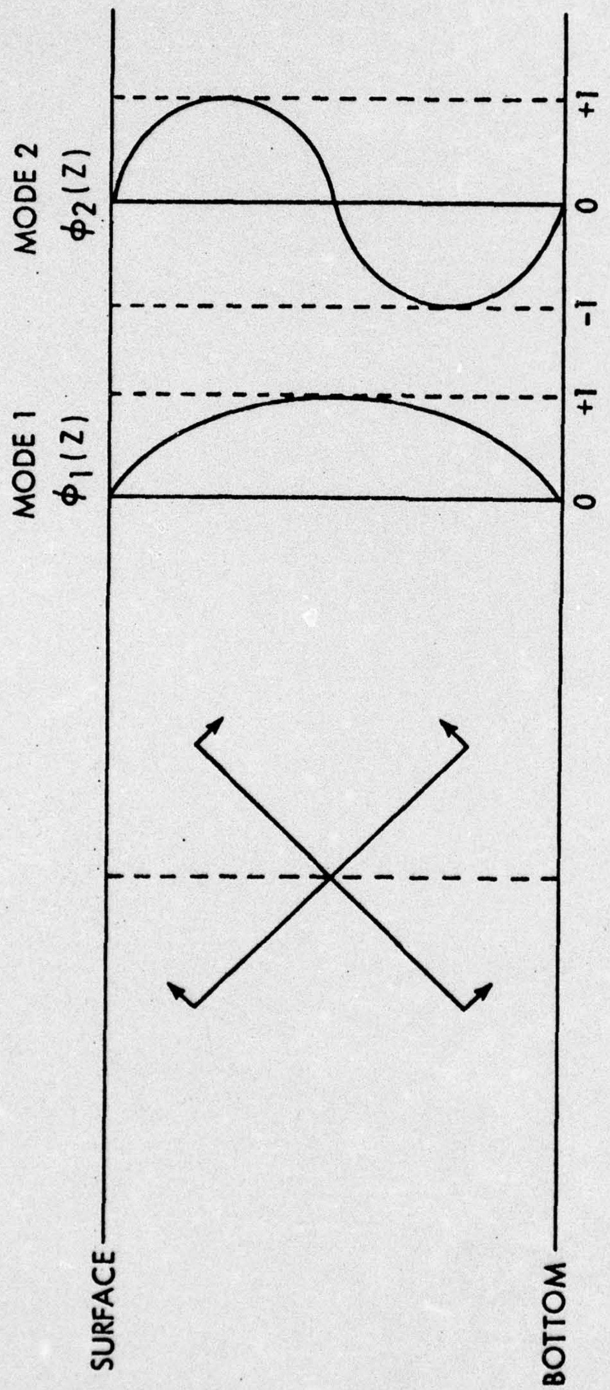
Figure 4



UPGOING AND DOWNGOING WAVES CORRESPONDING TO A MODE

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Figure 5

RELATIVE LEVELS OF MATCHED MODES (dB)

MATCHED TO AMPLITUDE	0.0
MATCHED TO AMPLITUDE (± 1)	-0.4
MATCHED TO PHASE	-1.3

Figure 6

	MODE (UNMATCHED)	AVERAGE RELATIVE LEVEL (dB) PHASE MATCHING	AMPLITUDE MATCHING	AMPLITUDE MATCHING (±1)
WINTER	1	-24.1	-39.5	-40.1
	2	-14.0	-35.5	-27.0
	3	-9.6	-32.4	-25.5
	4	-13.8	-30.9	-26.4
SUMMER	1	-15.2	-20.1	-25.4
	2	-14.4	-19.5	-19.8
	3	-8.8	-24.5	-22.4
	4	-9.8	-18.2	-15.3

AVERAGE RELATIVE LEVELS OF UNMATCHED MODES

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Figure 7